Waves and Optics - PHY204

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Ray Approximation and Reflection

Geometrical optics – Ray approximation

Light is an electromagnetic wave…and waves are difficult!

In many applications difficulties can be avoided and **geometrical optics** can be applied.

It is based on the suggestion that "**Light travels in straight lines called rays**".

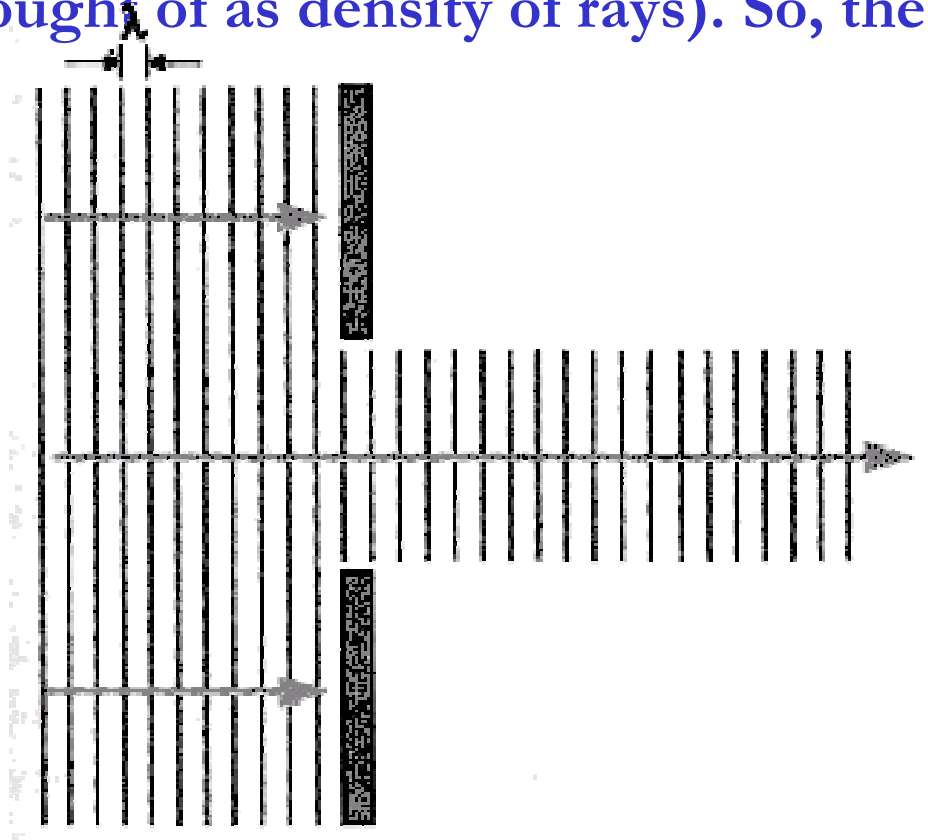
(These rays are perpendicular to the wave front)

This is the **ray approximation** and it reduces optics to ray tracing and geometry. Hence the name **geometrical optics**.

A ray is a line in the direction along which light energy is flowing. Physically we have **beam** (laser **beam** or a **beam** from your car's headlight). (Is it really a **bundle** of many parallel rays?)

Light waves can be reduced to rays?

Consider an unbounded plane wave of light.
All it takes to characterize it is its direction and intensity (which can be thought of as density of rays). So, the ray approximation is OK.

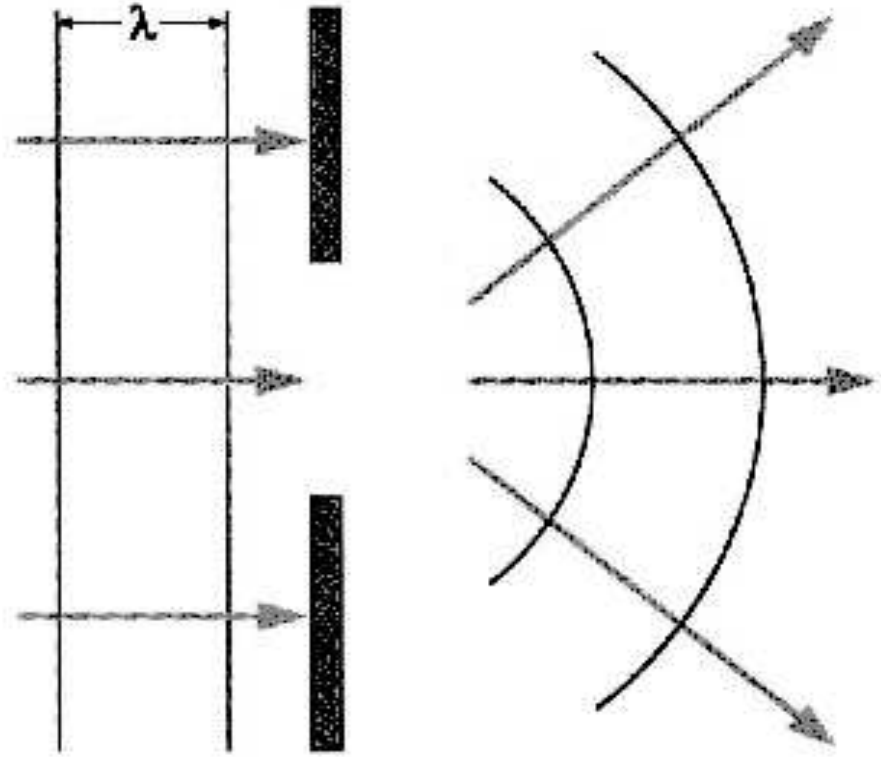


After passing through an aperture the plane wave becomes a beam and gets bounded.

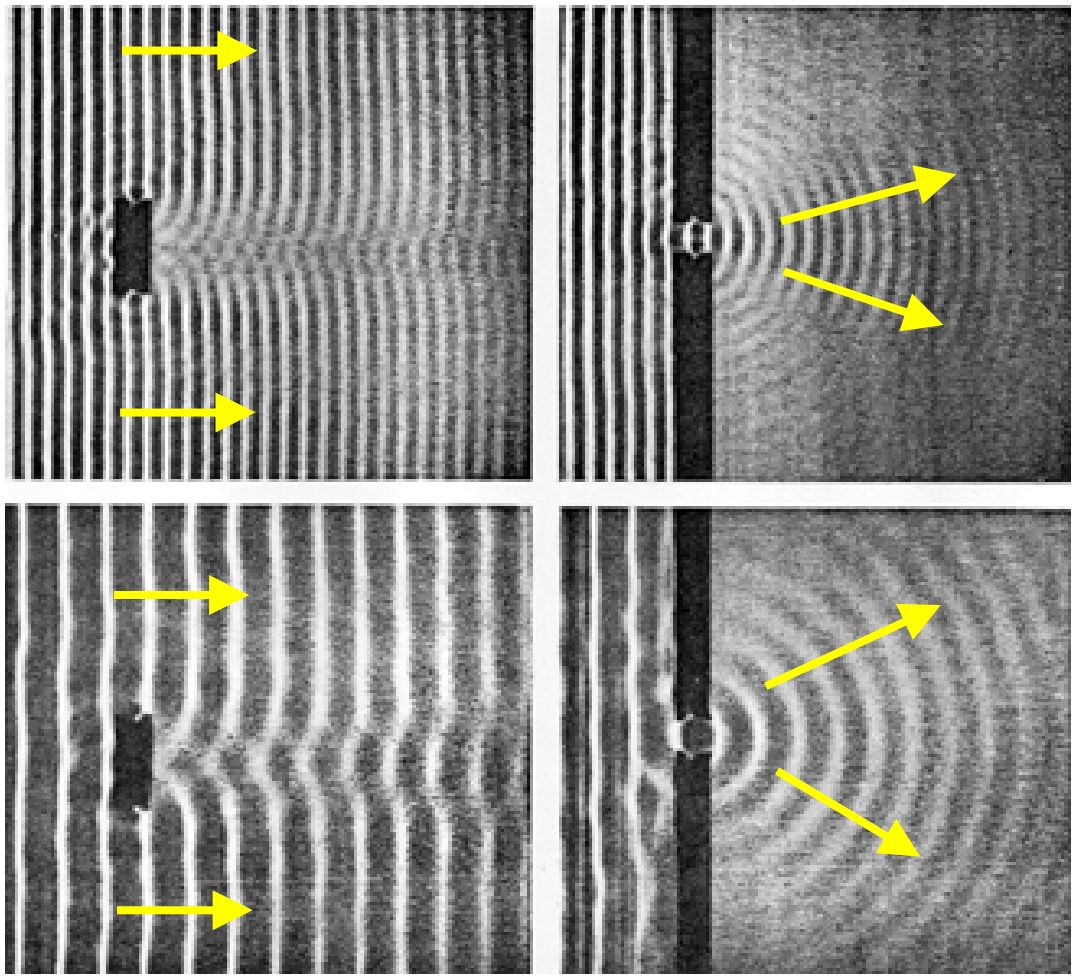
Does it keep going along a straight line?

Light waves can be reduced to rays? (2)

Depends on whether or not the aperture size is much larger than the wave length. If λ is on the order of the aperture, then diffraction occurs (later).



Ray approximation – waves on water surface



Waves propagate in straight lines unless they hit something (a barrier or an aperture) having a size comparable with the wave length.

This causes diffraction which we will study later.

The Ray Model (continued)

Light travels through a transparent medium in straight lines called **rays**, at speeds $v = c/n$, where n is the index of refraction of the medium.

Light **rays** do not interact with each other.

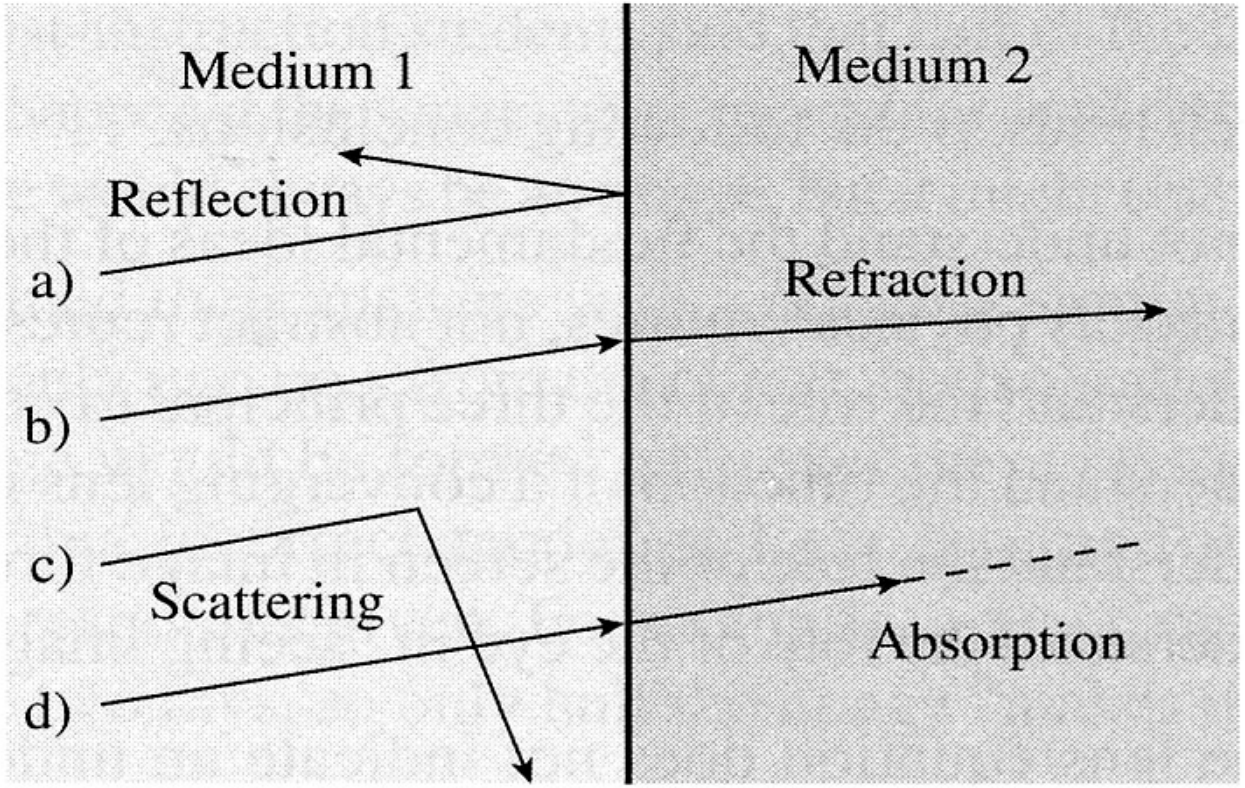
A light **ray** continues forever unless it has an interaction with matter that causes it to change directions or be absorbed.

Light has four different ways in which it can interact with matter:

-At an **interface** between two **media**, light can be **reflected** or **refracted.**

-Within a **medium** light can be **scattered** or **absorbed.**

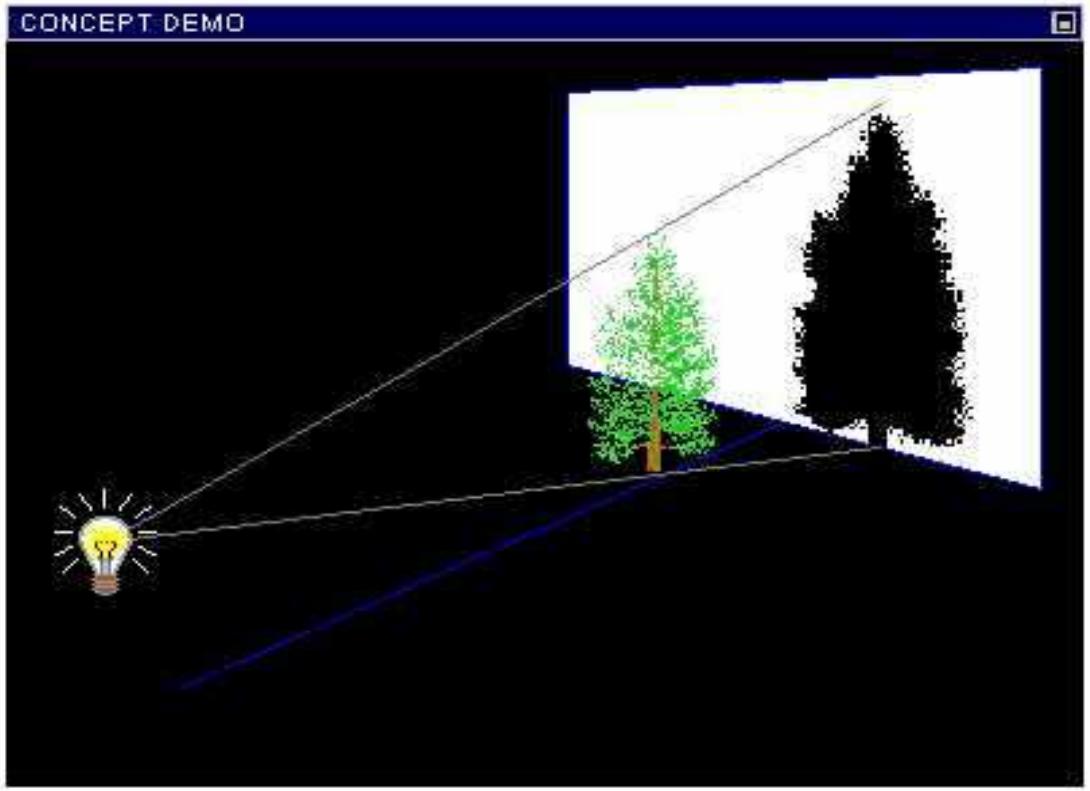
Four ways of interaction of light with matter



Light interacts with matter by a) reflection, b) refraction, c) scattering, or d) absorption.

Examples of using of the ray approximation:

A point source with a screen and 1D or 2D apertures between them What is the shape of the image on the screen? Image of what? What does it size depend on?



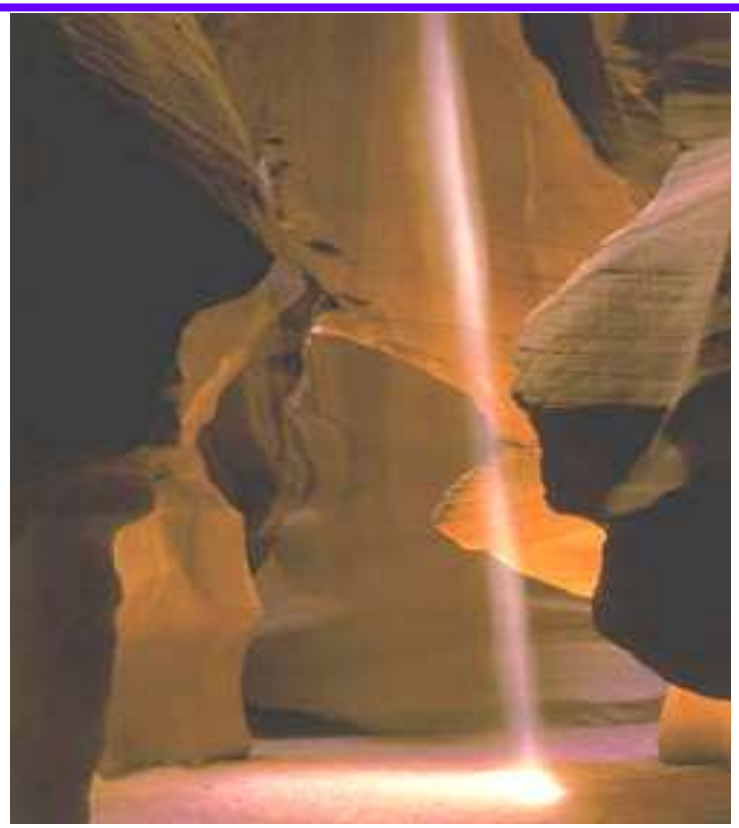
The shape of the image corresponds to the shape of the aperture;

The image is an image of the aperture;

Its size is proportional to the size of the aperture and to the ratio of distances:

$$\frac{\text{source to screen}}{\text{source to aperture}}$$

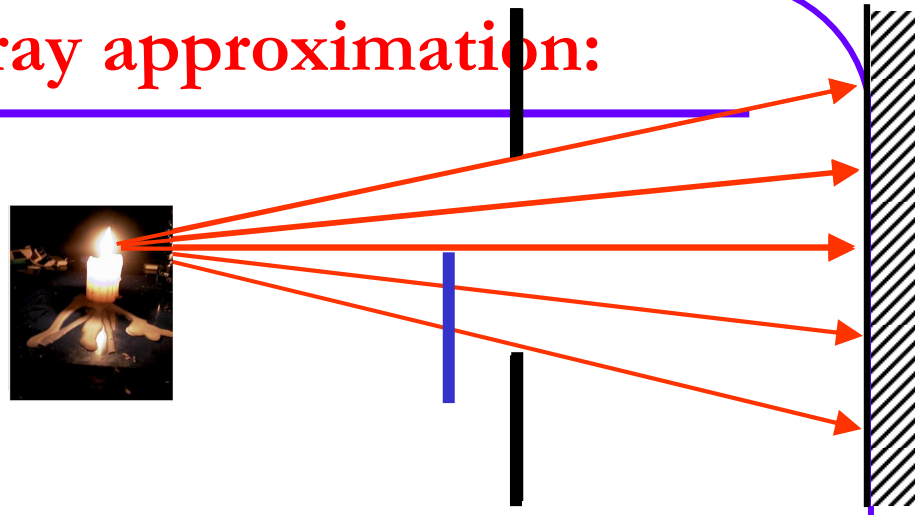
Image by an aperture and sunlight:



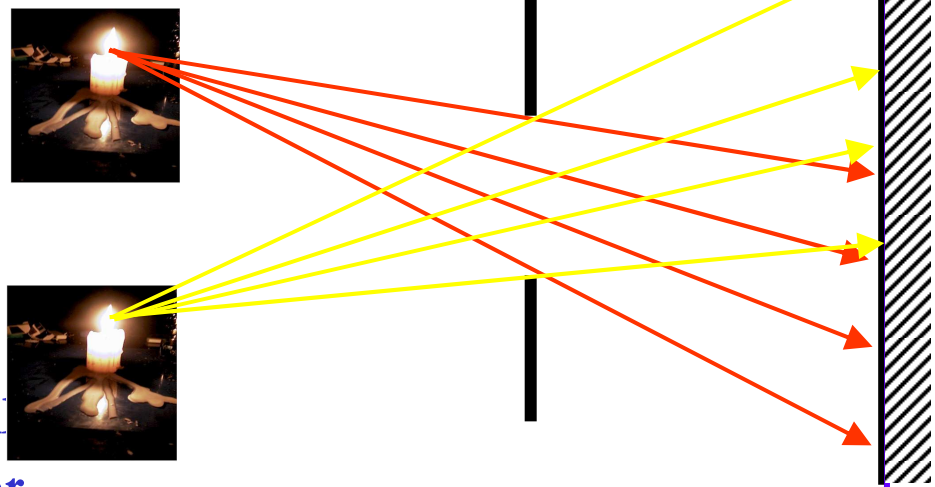
It is always the image of the aperture corresponding to its profile.
It is formed everywhere in space past the aperture (an opening, a window).
The image in a screen past the aperture is going to be rather sharp, wherever you put the screen.

Examples of using of the ray approximation:

1) How do you get a point source? What does it mean “rays filling the aperture”? What happens if we close half of the aperture?



2) Two point sources, an aperture and a screen. What kind of a pattern on the screen do they produce? What about a line of point sources?



3) A line of point sources and a very small (pinhole) aperture. What kind of image will be on the screen? What happens if we cover half of the aperture?

… the earliest model of photo camera, Camera obscura.

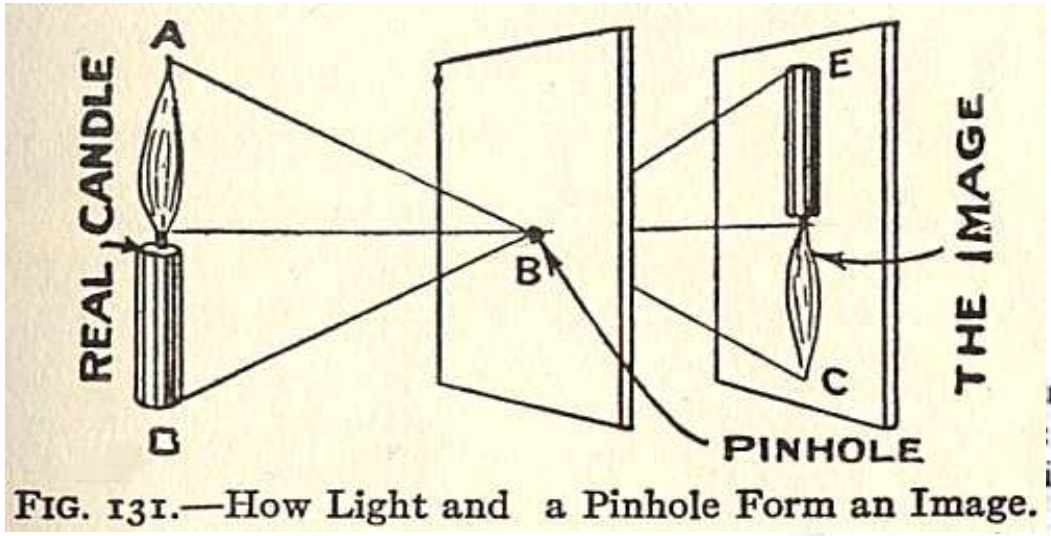
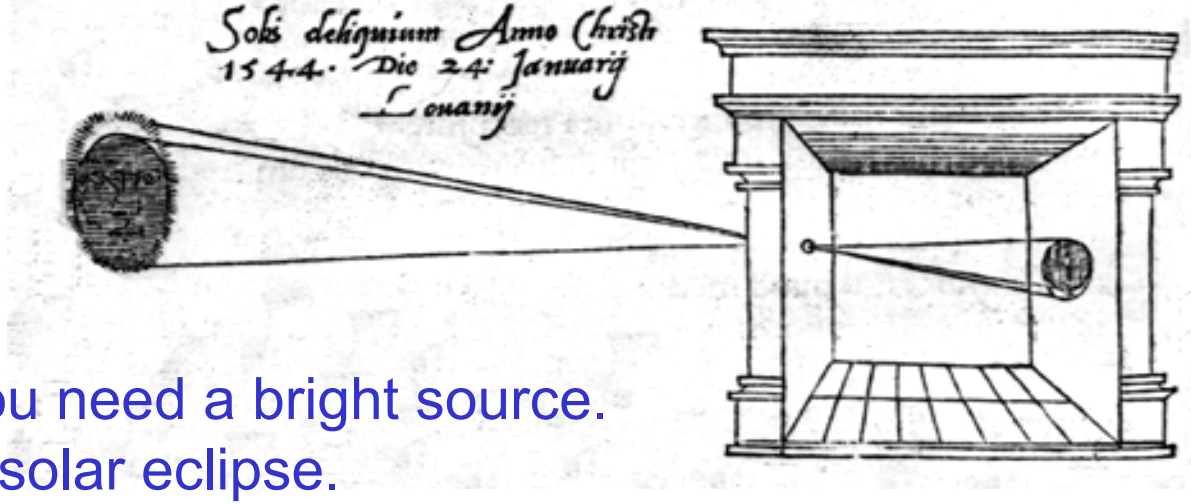


FIG. 131.—How Light and a Pinhole Form an Image.

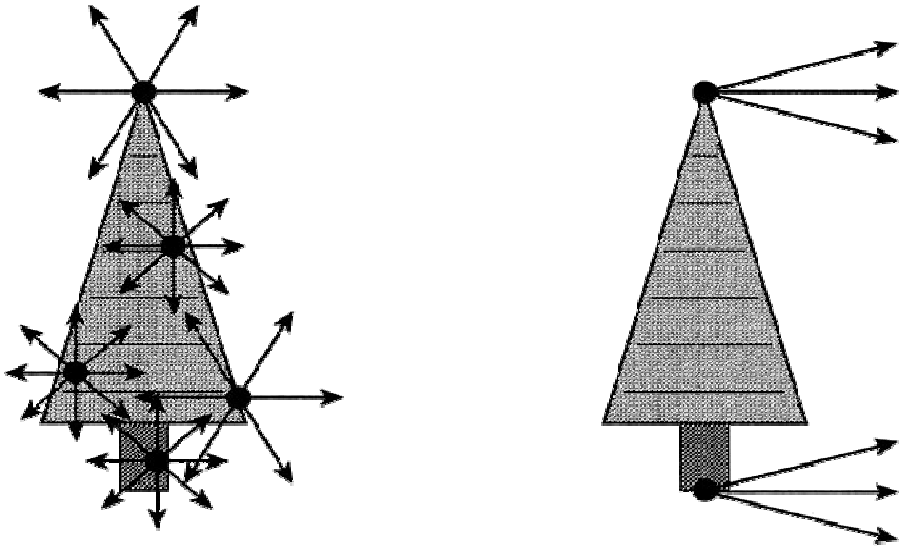
m in tabula per radios Solis, quàm in cœlo contin-
hoc eſt, ſi in cœlo ſuperior pars deliquiũ patiatur, in
iis apparebit inferior deficere, vt ratio exigit optica.



The primary problem is that you need a bright source.
A method to observe a partial solar eclipse.

Light emitted by not self-luminous "objects"?

- An *object* is a source of light rays. We make no distinction between self-luminous objects and reflective objects. Rays originate from *every* point on the object, and each point sends rays in *all* directions. This is shown in the figure below, which is pretty messy. To simplify the picture, we use a *ray diagram* that shows only a few important rays. A ray diagram does *not* imply that these are the only rays.

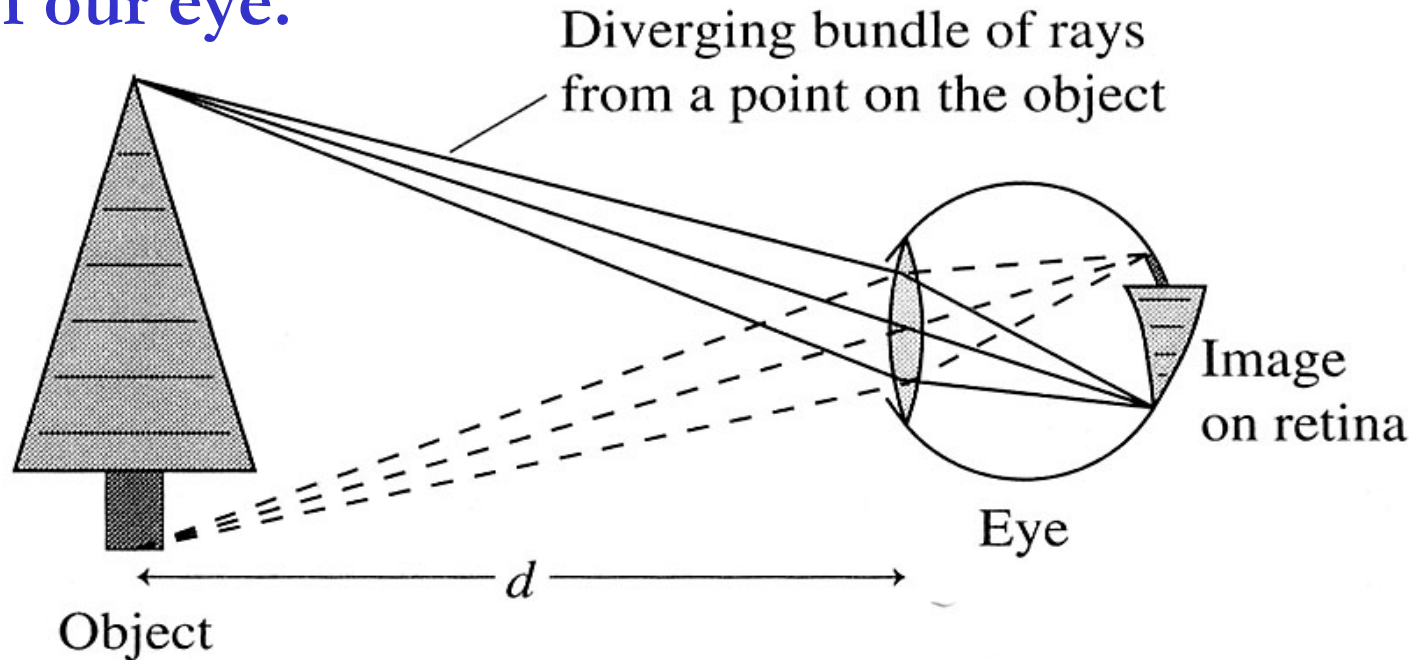


a) Reality b) Ray diagram

a) An object emits light rays in all directions from all points. b) A ray diagram is a simplified view.

How do we see objects?

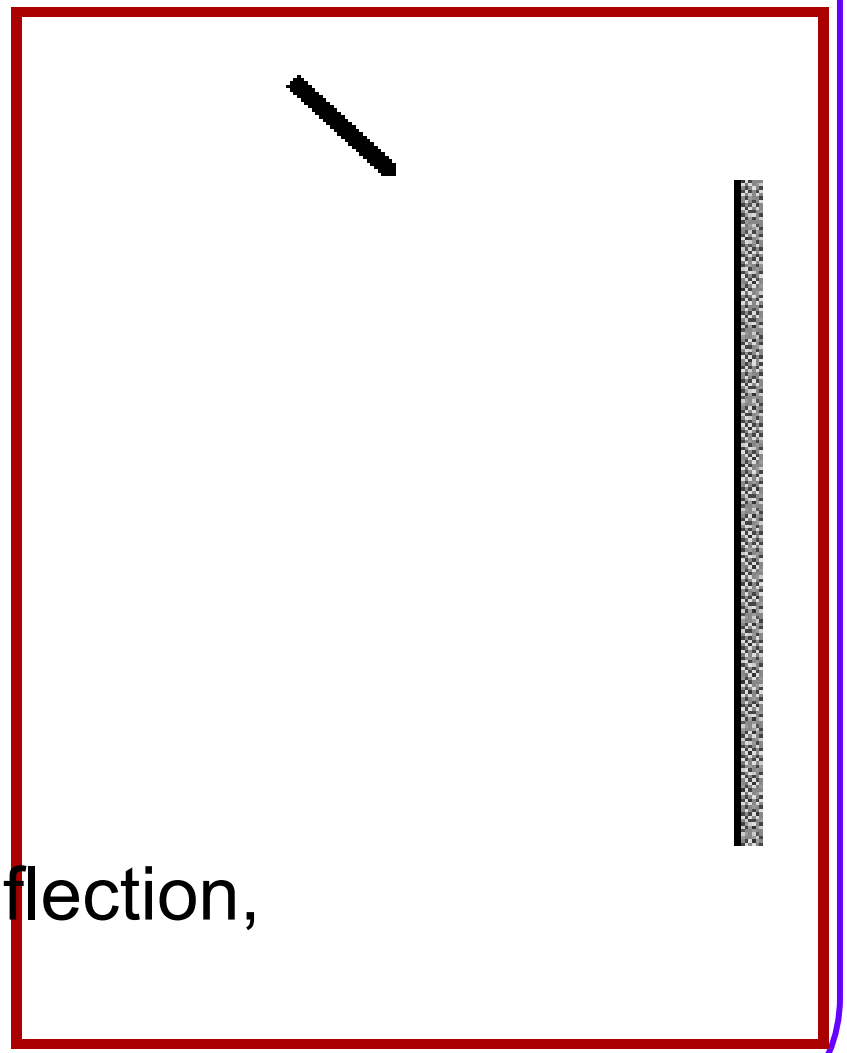
Our vision involves formation of images of objects on the retina of our eye.



The eye "sees" an object when bundles of diverging rays from each point on the object enter the pupil and are focused to an image on the retina.

Reflection of Light

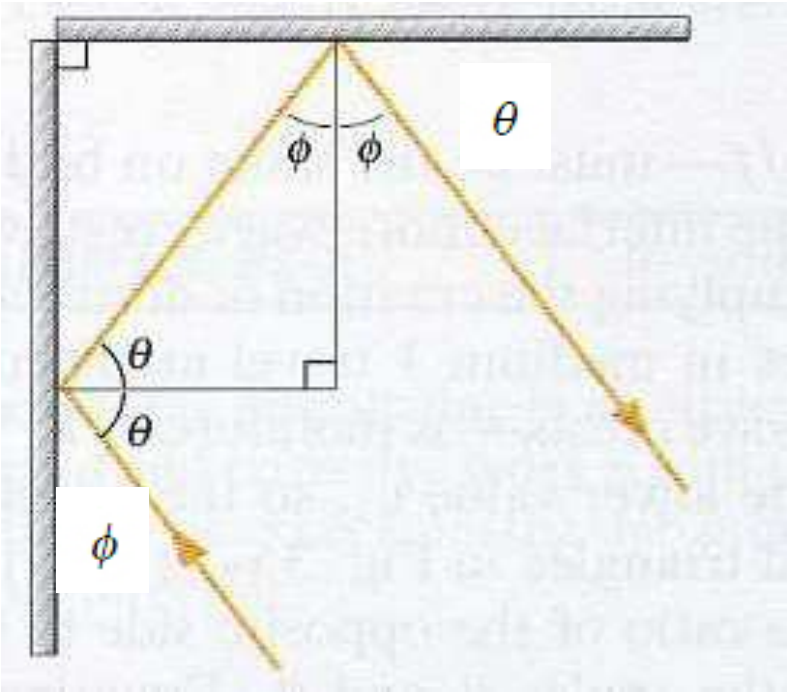
- A ray of light, the *incident ray*, travels in a medium
- When it encounters a boundary with a second medium, part of the incident ray is *reflected* back into the first medium



Angle of incidence = Angle of reflection,

$\theta_i = \theta_r$

Corner Reflector



From the geometry of the corner Reflector and the law of reflection

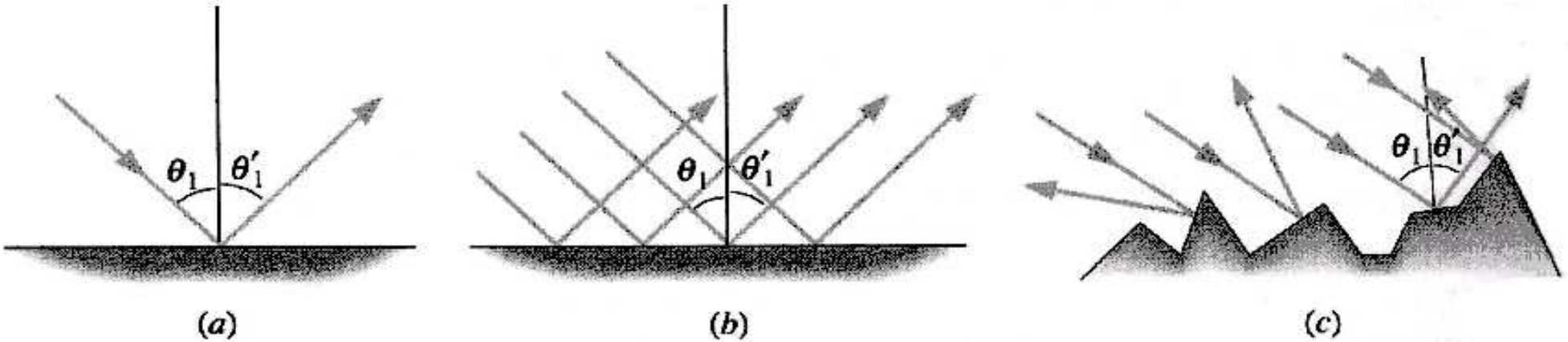
$$\phi = \frac{\pi}{2} - \theta$$

An incident light ray reflects in an anti-parallel direction independent of the incident direction!

Adding a third mirror at right angles forms a corner cube which returns any beam from which it came

Reflecting cubes left on the moon allows for laser-based measurements of the moon's distance to within *15cm!*

The law of reflection



Angles of reflection and incidence are equal (a). In specular reflection, a smooth surface reflects a light beam undistorted (b). A rught surface results in diffuse reflection (law of reflection still hold for each individual ray)

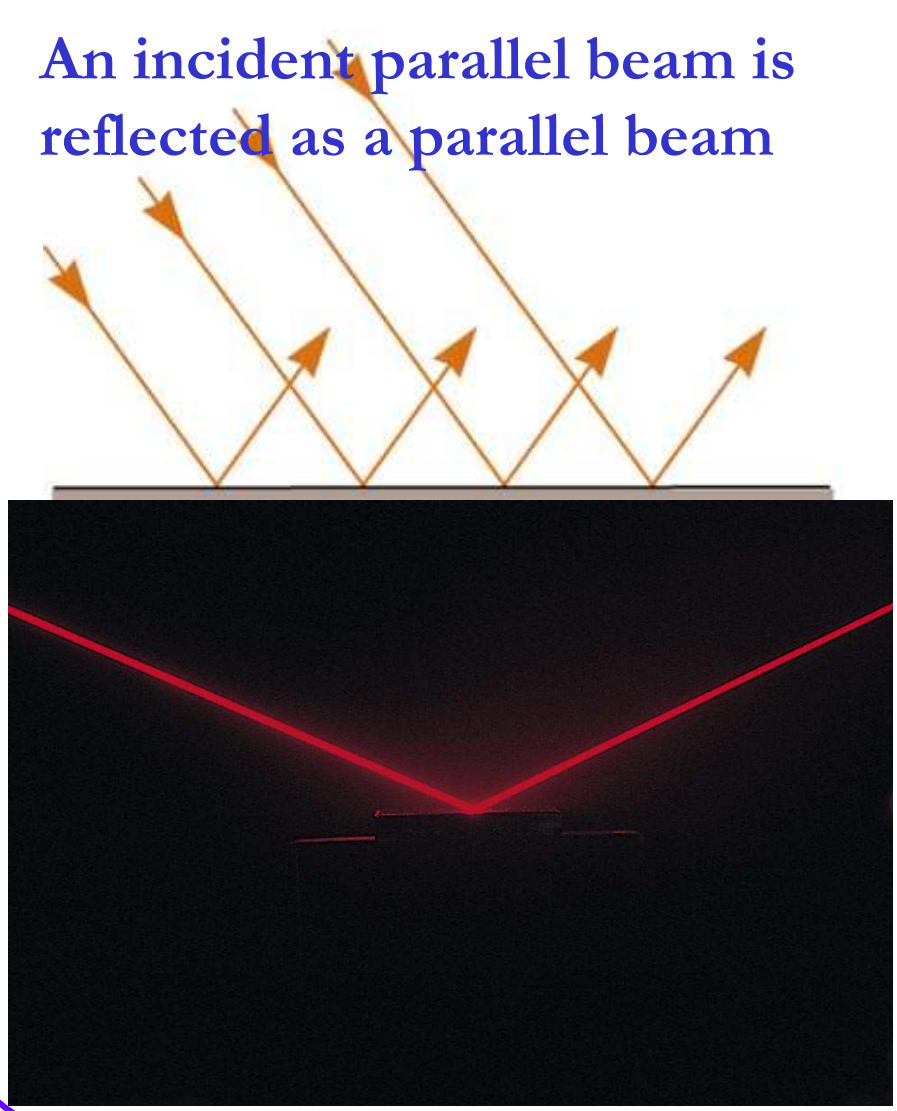
A single ray of light is incident upon a reflecting surface at an angle θ_1 with the normal to the surface.

It is reflected at angle θ_1' with the normal, such that $\theta_1' = \theta_1$.

The angle of reflection is always equal to the angle of incidence.

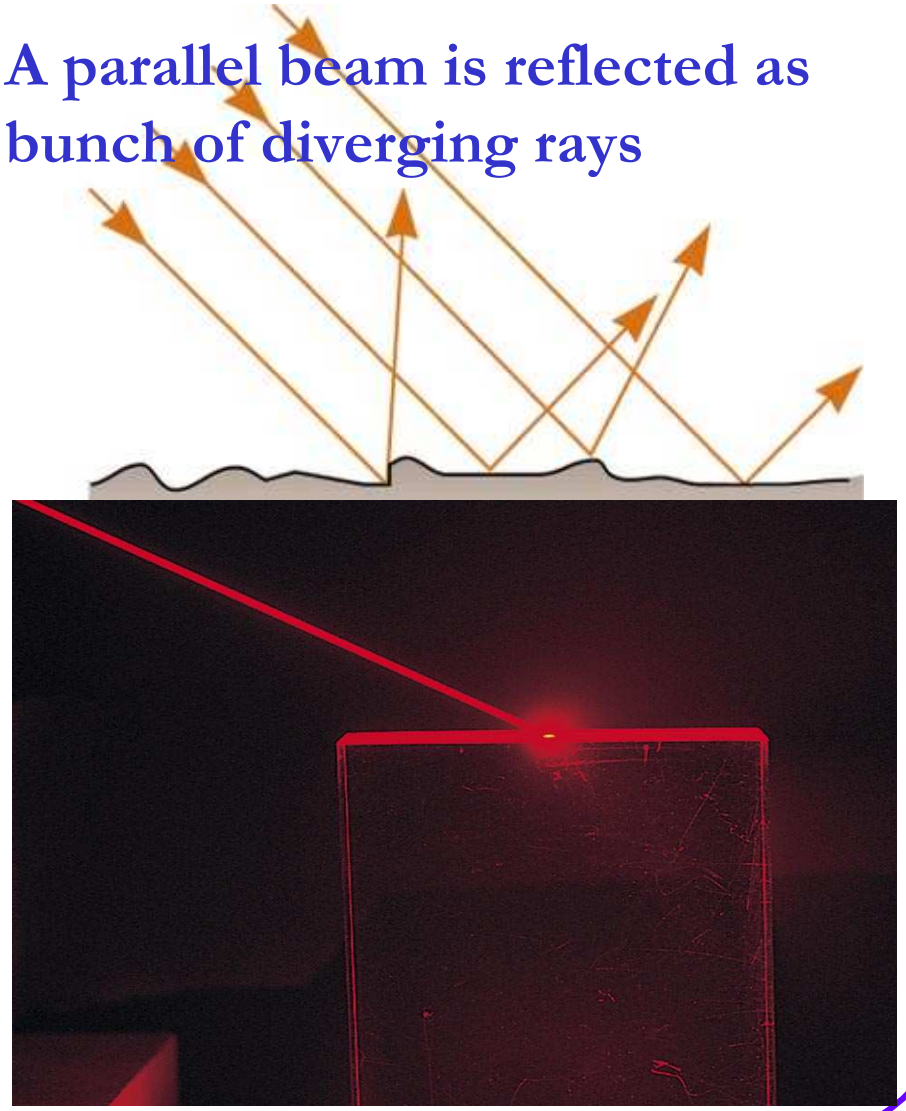
Specular reflection:

An incident parallel beam is reflected as a parallel beam



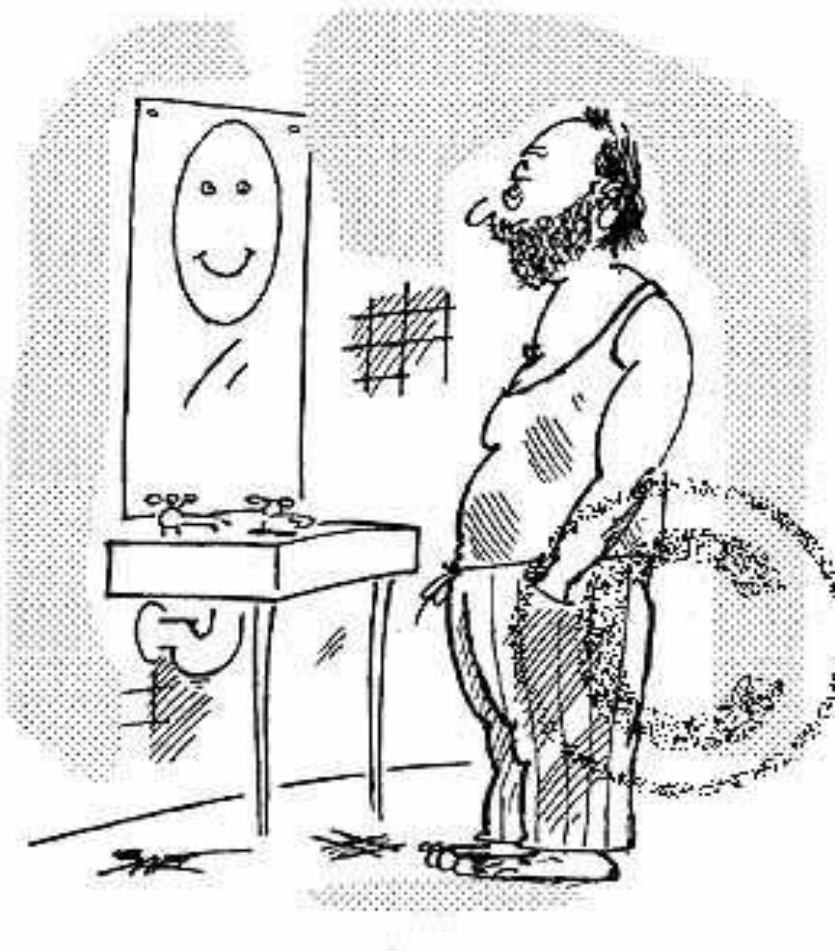
Diffuse reflection:

A parallel beam is reflected as bunch of diverging rays



What type of reflection is more useful?

Well, it depends, what you actually want to get…



Specular and Diffuse Reflection

Which part of the figure below shows specular reflection of light from the roadway?

With diffuse reflection you see the road**;**
With specular reflection you see **the** lights of the car **reflected off the road.**

Mirrors are designed to give specular reflection

Therefore the mirror surface is invisible by itself.
There are no point sources of light on mirror surface. Therefore, looking into a mirror you see reflections of objects, not the mirror itself.